Solid Oxide Fuel Cell Design Guide

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Background

In 1999, the U.S. Department of Energy, along with industrial teams and groups from the scientific community, established the Solid State Energy Conversion Alliance (SECA) to accelerate development of affordable solid oxide fuel cells. This guide was created to provide recommended design practices and associated modeling and analysis procedures to be used by SECA affiliated designers and fabricators of SOFCs to optimize the design of durable and reliable fuel cells.

This guide is based on past successful use of modeling tools to improve planar SOFC designs as well as advances in the state of knowledge. It describes suggested analytical procedures developed by the SECA Core Technology Program to model electrochemical and thermomechanical performance of SOFCs and how simulation tools can be used in designing a structurally reliable SOFC stack. The recommended modeling procedures presented in this guide attempt to account for the variability in material properties and design parameters of the essential elements in the SOFC structure. These modeling procedures capture the coupled physical phenomena of SOFCs by quantifying the electrochemistry activities and the associated thermomechanical behaviors of various SOFC components for different design configurations. This guide is intended to facilitate development of cost-effective, reliable, SOFC designs and is intended to serve as a repository for state-of-the-art knowledge and experience gained in SOFC designs as research and development continues.

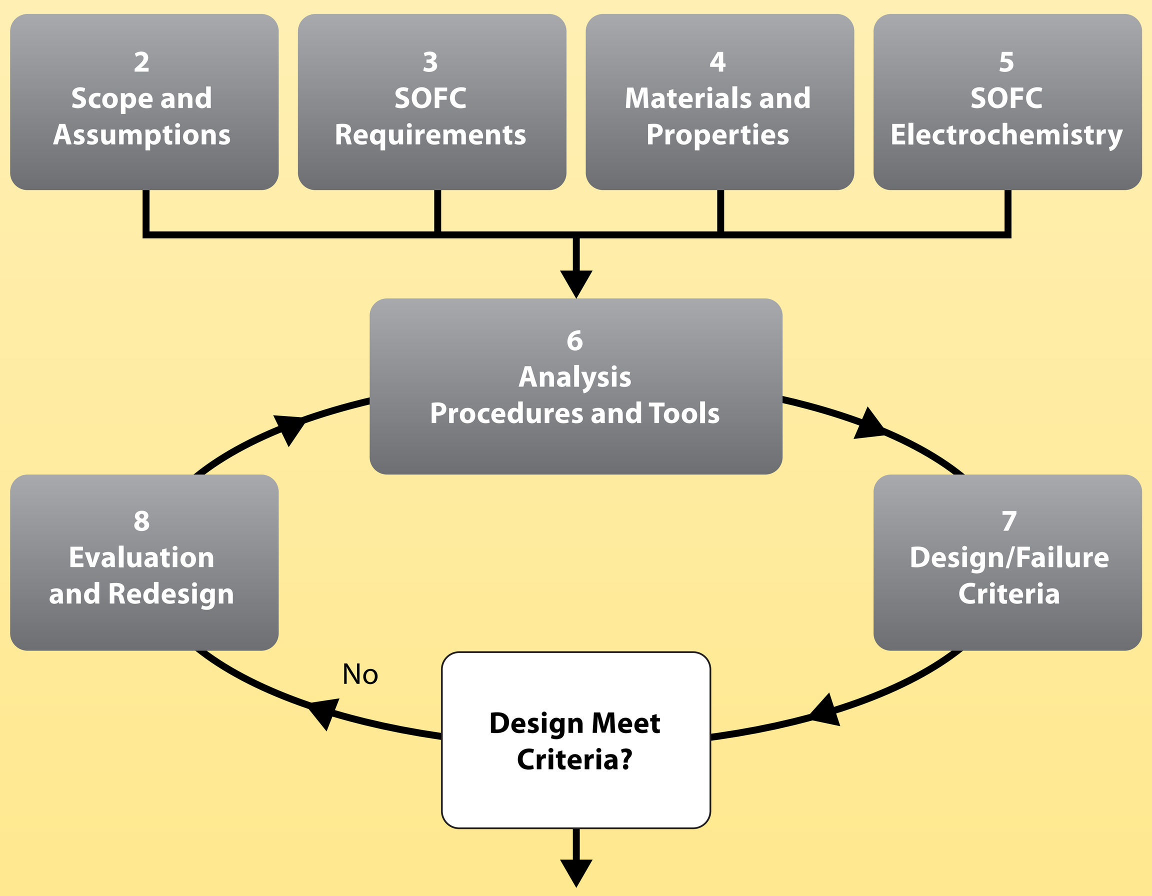


Figure 1: SOFC Work Flow Diagram

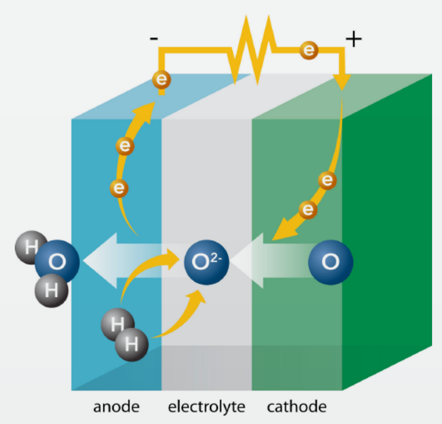
Approach

The technical approach taken here was to create a document that mirrors PNNL's stack design work flow. The guide is structured according to a design process work flow beginning with key inputs such as system requirements and material property data before beginning the iterative design process. The work flow of the document (and of the design process) can be grouped into two parts: 1) the development of the design envelope and 2) the iterative design process loop in which convergence to a working design may be achieved. High level descriptions are provided in the main body of the document with technical details listed in the appendices. Since many of the topics addressed by this guide are still under intensive research and development, this document will be a living document and revised as warranted.

Design Envelope

Scope & Assumptions / SOFC Requirements / Materials & Properties / SOFC Electrochemistry

Any design process must begin with a variety of inputs. The SOFC needs to be designed to meet numerous requirements, both of performance and operating conditions. The SOFC stack is a multi-component system containing many different materials that must be compatible and stable. It is also fundamentally an electrochemical device, and the thermomechanical state of the stack strongly depends on the electrochemical performance. By establishing the system requirements such as total power, power density, stack volume, gas flow and pressure drop and identifying material sets with acceptable properties and electrochemical performance, etc., all of these inputs come together to define the working design envelope.



Schematic of Ion Conduction and Electrical Current Flow in an SOFC.

The work flow of the document begins with the upper row of elements as shown in Figure 1: Scope & Assumptions, SOFC Requirements, Materials & Properties, SOFC Electrochemistry. These key inputs are steps in the work flow diagram that also correspond to a respective chapter within the guide.

Scope and Assumptions – describe a set of limiting assumptions relevant to the analyses described in this guide.

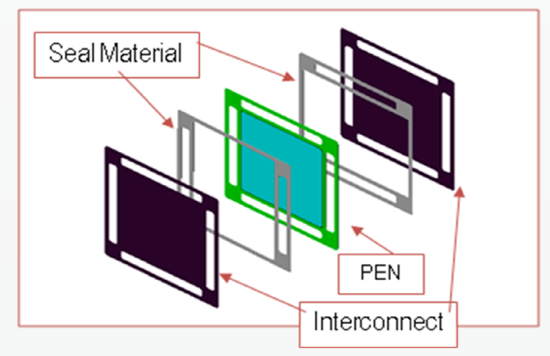
SOFC Requirements – describe the requirements that most strongly influence SOFC design.

Materials and Material Properties – discusses commonly used materials for SOFC components and key materials properties needed. It also discusses the solid material properties required and the models to which they apply. Details and descriptions of methods used to determine material properties for many SOFC materials currently used are provided in the appendix.

SOFC Electrochemistry – provides background and a summary of how the electrochemical performance model is assembled for the various reactions that occur in an operating SOFC and used for analysis of the stack.

Iterative Design Process

Analysis Procedures & Tools / Design/Failure Criteria / Evaluation & Redesign



The second part of the work flow in the design guide is the iterative design process loop as shown in the lower elements in Figure 1. After an initial design is prepared, it must be analyzed to establish the thermomechanical state of the SOFC stack. Once the stack has been modeled, its state must be compared to a set of design and failure criteria to establish whether the design is successful. If the design results exceed the failure criteria specified (e.g., the local stress in a cell exceeds the failure stress, causing cracking), then the design must be modified. Any changes implemented, whether it be geometrical, operational, or material, must be evaluated and the design process repeated. Again, these steps correspond to a respective chapter within the guide.

Analysis Procedures & Tools – describes the various analysis tools needed and the physics required to sufficiently model the stack. It also provides insight regarding issues to be aware of during model setup; key elements required to provide good thermal management; how to implement custom material property data into the models; and a discussion on PNNL-developed SOFC modeling procedures that have been implemented into commercially available modeling tools.

Design/Failure Criteria – describes failure criteria and provides guidelines for safety factors to be used in SOFC design.

Evaluation & Redesign – the analysis tools in the Analysis Procedures & Tools Chapter and the failure criteria described in the Design/Failure Criteria Chapter provide methods to evaluate the SOFC design as described in this chapter. This chapter also provides guidelines for improving the design showing relationships and sensitivities between design parameters and the resulting thermomechanical state of the SOFC.

Conclusions

During this year, Pacific Northwest National Laboratory in collaboration with the National Energy Technology Laboratory, Oak Ridge National Laboratory, and the American Society of Mechanical Engineers Codes and Standards Technology LLC have developed a design guidance document that provides SECA affiliated designers and fabricators with recommended design practices and associated modeling and analysis procedures to optimize the design of durable and reliable planar SOFCs. The guide is structured according to a design process work flow beginning with key inputs such as system requirements and material property data before beginning the iterative design process.

Future direction of this document includes a peer review as directed by the DOE project manager and release of this initial version design guide document.

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